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ENVIRONMENTAL PROTECTION AGENCY

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SEATTLE, WASH.

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SUMMARY REPORT

NITROGEN SUPERSATURATION IN THE COLUMBIA AND SNAKE RIVERS

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ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAMS
SEATTLE, WASHINGTON
REGION X

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INTRODUCTION

Evidence strongly indicates that the future of salmon and steelhead in the Columbia and Snake Rivers is seriously jeopardized by high levels of nitrogen supersaturation in these waters during spring fish migration periods. Under present conditions, toxic concentrations of dissolved nitrogen persist from the most upstream dams to the mouth of the Columbia River during periods of spill.

The anadromous fish of the Columbia Basin, a major regional and national resource, could be reduced to 10 percent of its present size within three years. The urgency of this situation requires that immediate action be taken by Congress and Federal agencies to implement an aggressive strategy for an early and effective reduction of dissolved nitrogen concentrations in the Columbia and Snake Rivers. Also, since this reduction may take several years to accomplish, a concurrent program of interim measures to reduce the exposure of migrating salmonids to the existing high nitrogen levels must also be established.

Nitrogen supersaturation has been shown to be a toxicant which causes mortality to aquatic life and as such, violates the Interstate Water Quality Standards criteria adopted pursuant to the Water Quality Act of 1965. In accordance with the responsibilities transferred to the Environmental Protection Agency, as set forth in Executive Order 11507 of February 4, 1970, Mr. William D. Ruckelshaus, Administrator, directed the Northwest Regional Office of the Environmental Protection Agency to prepare a report outlining the scope of the problem in the Columbia Basin with recommendations for its solution.

The objective of this report is to summarize the major findings and recommendations of a more detailed technical report (available on request from Environmental Protection Agency, Region X). Courses of action are explored to implement the short- and long-term solutions to the nitrogen supersaturation problem.

EFFECTS ON FISH

Nitrogen supersaturation and its effect on fish (gas bubble disease) has been known since before 1900 but has primarily been associated with fish hatchery operation. Only in recent

years have the mysterious disappearance of adult salmon and steelhead between the dams and the losses of juvenile downstream migrants been associated with high levels of dissolved nitrogen. The relationship between migrant fish mortalities, nitrogen supersaturation, and reservoir spillage has now been well documented by field observations and laboratory studies. Nitrogen supersaturation and resultant gas bubble disease were implicated in an estimated loss of 20,000 summer chinook salmon between Bonneville Dam and McNary Dam on the Columbia River in 1968 (see Columbia River Basin Map, Figure 1). Similarly, high spillway discharge at Lower Monumental and Little Goose Dams was the primary factor in an estimated 70 percent loss of Snake River downstream migrants during the spring of 1970. Dams have converted the Columbia River from a flowing stream into a series of slow moving reservoirs, which retard the outmigration of juvenile salmonids to the ocean and thereby subject them to increased stresses, including temperature, diseases, predation, and high nitrogen levels.

CAUSES

Nitrogen supersaturation in the waters of the Columbia and Snake Rivers is caused when river flow must be passed over the spillways of the main stem hydroelectric dams. Air, which is 79 percent nitrogen, is entrained in the flow as it passes over the spillways and, as the water plunges into the deep stilling basin below the dams, the increased pressure and turbulence force the gasses in the air to dissolve in the water. Under these conditions the water may contain dissolved nitrogen and other gasses much in excess of surface equilibrium concentrations. Nitrogen concentrations up to 147 percent of surface equilibrium values have been observed below spillways under these conditions. Water passing through the power-generating turbines at the dams, or through other non-air-entraining facilities, does not increase in nitrogen content.

In a free-flowing river, with normal turbulence, the supersaturated water would soon equilibrate with the atmosphere and tend to produce a solution in which concentrations of dissolved gasses are roughly 100 percent of their normal saturation values. The construction of dams on the Columbia and Snake Rivers, however, has converted these rivers from free-flowing streams into a series of reservoir pools, reducing mixing and exposure of the liquid to the atmosphere, and retarding the dissolution of the gasses and return of the supersaturated water to equilibrium.

Figure 1. Columbia River Basin Map

In some cases, the series of dams can have an accumulative effect, increasing nitrogen levels at each successive dam downstream. In the more general case, the effect of most dams is to reinforce and maintain a supersaturation level, thereby offsetting the limited amount of equilibration which occurs between dams.

Spilling occurs at a hydroelectric project when total river flow exceeds the volume which can be passed through the turbine generator units to produce power. Therefore, during the periods of high runoff in the spring and early summer, spilling often occurs for prolonged periods at most of the dams in the system. Even during periods of lower flows, spilling at many projects occurs because of the differences in hydraulic capacities of turbines among the various main stem hydroelectric projects. There is relatively little usable storage capacity available in most of these "run-of-the-river" projects on the Columbia and Snake Rivers. Consequently, flows past one dam are roughly equal to the release at the first upstream project plus any tributary inflow between the two. This means, for example, that if Wells Project (Douglas County Public Utility District) on the middle Columbia, were passing flows through its turbines equal to their capacity of 230,000 cubic feet per second (cfs), Rock Island (Chelan County Public Utility District) downstream, with a present turbine capacity of only 80,000 cfs, would have to pass at least 150,000 cfs over its spillway.

Regional power demands on the network of generating facilities also may act to limit the amount of flow which can be passed through turbines and thereby affect the amount of spilling required. With the present hydraulic design of turbone generator units in the Columbia system, it is not practical to allow them to pass water without generating power. Passing flow through these units with low loads produces cavitation and potential damage to turbines and water passageways. Operating units in this manner has also been shown to produce high mortality rates in downstream migrant fish which pass through the units. It is the total energy load then--not the hydraulic capacity-- that presently determines how much water can te passed through the turbines. Unfortunately, the annual period of lowest power demand coincides with the spring-summer period of highest river flows and peak fish migration. Recognizing this, the Corps of Engineers and Bonneville Power Administration are currently conducting studies to devise methods of increasing

power exports and operating turbine-generator units at very low loads.

Storage in reservoirs located principally in headwater areas of the Columbia and Snake Rivers is used to regulate downstream flows. However, even with the addition to the system of some 19 million acre-feet of active storage in Mica, Libby, and Dworshak Reservoirs (now under construction), the average-year floods in the Columbia Basin will still require spill at some projects. Significant spilling and high nitrogen levels can be expected in the future, assuming the reservoirs and power generation facilities are operated within existing constraints. The use of the available reservoir storage specifically for reduction of spilling and nitrogen levels during the spring and early summer flood flow period is generally compatible with use of this storage for power generation, flood control, navigation, and irrigation. Flexibility in the operation of the reservoir system was demonstrated through an unprecedented cooperative effort of the Corps of Engineers, Bonneville Power Administration, state and federal fisheries agencies, and public utility and private hydroelectric project operators, in a program to reduce spilling during a five-day period in April of this year to improve nitrogen conditions during a massive release of hatchery-reared juvenile chinook salmon and steelhead trout. Additionally, juvenile chinook salmon and steelhead trout migrants were captured at Little Goose Dam in an experimental program and transported downstream by truck for release below Bonneville Dam to demonstrate the feasibility of this method to reduce exposure of the fish to excess nitrogen and help minimize losses of the Snake River run. Limitations on the flexibility of the reservoir and power system include economic losses due to loss of some power revenues, and costs from potential increased flood damage. Legal complications include certain conditions imposed on the operation of reservoir storage in Canada under the terms of the Columbia River Treaty of 1964, contractual agreements for operation of public utility and private hydroelectric projects, and commitments in Bonneville Power Administration contracts for power distribution and marketing.

The Corps of Engineers, National Marine Fisheries Service, Bonneville Power Administration, and Oregon and Washington fisheries agencies have worked diligently during the past year toward the development of short-term and long-range solutions to the problem of nitrogen supersaturation. Research and development efforts have been concentrated in the areas of operational and structural modifications to the regional

reservoir and power generation system to reduce spills and nitrogen concentrations; modifications in hatchery release schedules; capture and transport of migrants around reaches of critical nitrogen levels; cause-effect relationships between spillage, dissolved nitrogen concentrations, and gas bubble disease, and monitoring and analytical procedures for measuring and predicting nitrogen supersaturation levels. The Corps of Engineers has developed and successfully tested on prototype scale, a scheme for passing an additional 60,000 cfs through empty turbine bays in the Lower Snake River dams. This will reduce considerably the amount of spills and nitrogen entrainment at those projects. An additional spillway modification (flip bucket) that could be added to an existing project shows promise for reduction of nitrogen. The effect of this device would be to prevent low to moderate spillway flows from plunging deeply into the stilling basin.

However, even if the operational and structural measures demonstrated to be feasible to date could be fully implemented, the nitrogen levels in years of average or higher flows will continue to be high enough to constitute a serious hazard to juvenile and adult anadromous fish migrating in the Columbia and Snake Rivers. To insure the safety of this major fishery resource, an effective strategy for reduction of nitrogen levels to safe concentrations must be developed and implemented, along with measures to minimize exposure of migrant fish to the existing and future high levels of nitrogen. The following conclusions and recommendations are pertinent to this strategy and are supported in the technical report.

CONCLUSIONS

1. Essentially all reaches of the Columbia and Snake Rivers downstream from hydroelectric dams are significantly supersaturated with dissolved atmospheric gasses during periods of high spillway discharge.

2. The salmon and steelhead runs in the Columbia and Snake Rivers are seriously jeopardized under present conditions by supersaturation of dissolved gasses.

3. Nitrogen supersaturation conditions in the Columbia and Snake Rivers are caused at main stem hydroelectric dams when river flow must be passed over the spillways during the spring flood period. Nitrogen in the air is entrained in the

flow as it passes over the spillway and, as the water plunges into the stilling basin below the dam, increased pressure forces the nitrogen from a gaseous state into solution in the water.

4. Water passing through the power-generating turbines or otherwise not exposed to the aerating effect of the spillways does not become supersaturated with nitrogen.

5. Nitrogen supersaturation levels above 105 percent produce symptoms of gas bubble disease in fish, and levels above 120 percent are lethal.

6. Nitrogen, because of its greater proportionate volume in air, has been measured and related to toxic effects on fish. However, it is known that the other atmospheric gasses are also involved in the gas bubble disease phenomenon.

7. Hypothetical flow regulation studies show that, with no operational or structural modifications for control of nitrogen, spillway flows at existing dams will be great enough to produce lethal levels of nitrogen supersaturation in years of average and higher river flows, but not in low flow years. An average year is one with flows which, statistically, would be equalled or exceeded one year out of two. Although it is not certain at what specific river flow levels nitrogen problems begin to occur, it is apparent that the threshold level is somewhere between low and average flows.

8. Under present plans to expand the Columbia Basin hydroelectric system through the year 1980, the volume of spills at the various projects will be reduced. However, without additional control measures, the reduction in the volume of spills will not be great enough to reduce nitrogen supersaturation to levels considered safe for fish during even a year of average flows.

9. Installation of slotted gates and bypass of flow through empty turbine bays in the Lower Snake River dams will further reduce the spills in that river, but nitrogen levels hazardous to fish will still occur in years of average or higher flows.

10. A basic requirement to a solution of the problem is to devise methods whereby volume in excess of flows through turbines can be passed by dams without entraining atmospheric gasses.

11. Lower Granite Dam, presently under construction, will add to already critical nitrogen problems in the lower Snake River unless the completed project includes provisions for passing flood flows without entraining atmospheric gasses.

12. Unless provisions can be made to pass maximum flows through turbines, installation of turbine generator units in dams before they are needed to meet regional power demands may eliminate flexibility in the use of the otherwise empty turbine bays to bypass flow, and thus may aggravate the nitrogen problem.

13. Increasing use of the hydroelectric system for peak power generation could cause wide diurnal fluctuations in the amount of spilling unless pumped storage, pondage, and thermal power facilities are effectively used to reduce the fluctuations.

14. The critical nature of the problem in 1971 caused an unprecedented level of coordination and cooperation among the Corps of Engineers, Bonneville Power Administration, and the Northwest fishery agencies in developing partial immediate solutions to the problem.

15. Flexibility within the federal dam-power complex contributed much to the success of a flow reduction program in April 1971 to make the best conditions for a mass hatchery fish release. Although the program required increased coordination, the cost to the Government was minimal. Continued annual use of the flexibility of the federal system is a necessary partial solution to the nitrogen problem.

16. The Washington Public Utility Districts and Idaho Power Company cooperated in the nitrogen reduction program in 1971, but even greater interchange between the federal and non-federal systems should be permitted by necessary changes in regulations and licenses. It is necessary to include the Federal Power Commission in future planning.

17. Trapping of downstream migrants from the Snake River and transport to the estuary are a necessary partial solution to the problem. Additional trapping at McNary Dam would salvage fish from the upper Columbia and residual from the Snake River.

18. Delay in passage of adult upstream migrants below the dams and in fishways is a significant factor in increasing mortalities from direct or secondary effects of gas bubble disease. Changes in the water management system within allowable flexibility could relieve the adult fish delay problem.

19. Nitrogen conditions are more severe at some dams than at others because some necessitate more spilling than others. Also, spillway and stilling basin designs have an effect. Dams newly completed have required almost complete spilling of flood flows until the power-generating turbines are installed--for example, at John Day Dam, completed in 1968.

RECOMMENDATIONS

1. The states of Oregon, Washington, and Idaho, together with the Environmental Protection Agency, should initiate immediate action to establish a water quality standards criterion for dissolved nitrogen in the Columbia and Snake Rivers.

   a. The standards criterion should establish a maximum allowable concentration of dissolved nitrogen in the Columbia and Snake Rivers at 110 percent of saturation based on analytical procedures presently being followed by the National Marine Fisheries Service.

   b. Immediate research and development efforts should be initiated to develop a method to measure total dissolved gas partial pressures to be related to dissolved gas concentration data.

   c. Expanded research and development efforts are also needed to relate dissolved gas partial pressure data to effects on fish. The results of these studies may be used for future reviews of the standards criterion for nitrogen.

   d. The Environmental Protection Agency should work with the National Marine Fisheries Service to develop an effective regional program for dissolved nitrogen monitoring in the Columbia and Snake Rivers. A formalized monitoring program will be needed to measure progress towards compliance with the standards criteria.

2. A regional council should be established immediately to make specific recommendations on administrative, legislative, and policy actions required to implement an effective nitrogen control program. Membership on the council should include high-level representatives of regional environmental, fisheries, water resource development, and water management agencies. The regional council for nitrogen control should periodically report on its review of the nitrogen supersaturation problem, assessment of progress towards control of nitrogen supersaturation effects on fish, and recommendations for further action to the council's constituent agencies, the Council on Environmental Quality, and other affected agencies. Elements of a regional nitrogen control program should include the following:

a. Nitrogen supersaturation reduction program.

(1) Maximum utilization of the flexibility of the regional system of reservoirs and power-generating facilities to reduce spills during periods of fish migration.

(2) Provisions at each dam of a method to pass any flows which are in excess of those required for power generation through or over facilities which will not entrain excessive atmospheric gasses in the water. The Corps of Engineers should be fully supported in their suggested program of structural modifications for this purpose at their projects and others.

(3) Revisions of generator installation schedules and construction methods to maintain maximum bypass capability at dams during the period of construction. Congressional authorization and appropriation schedules may need to be adjusted appropriately.

b. Expanded program to physically limit exposure of migrating juvenile salmonids to nitrogen supersaturated waters.

(1) Expand the installation and operation of fish collecting screens in all turbine units at Little Goose Dam by April 1972. The collection screens could later be

transferred to Lower Granite Dam at the time of its completion. Lower Granite should be designed to allow the installation and operation of both skeleton bays and fish collection screens.

(2) Install and operate fish collection screens in all turbine units at McNary Dam by April 1973.

(3) Continue to expand the program initiated in 1971 to make mass fish hatchery releases during periods of reduced nitrogen. Transport fish, where feasible, for release in the Lower Columbia River below Bonneville Dam.

3. Any new dam in the Columbia Basin must include facilities for adequate control of nitrogen supersaturation. Specifically, adequate controls at Lower Granite Dam (now under construction) must be provided before completion of this project. The design goal for these control facilities should be to maintain dissolved nitrogen concentrations downstream from the project below 110 percent of saturation in a ten-year flood.

Additionally, existing plans for further alteration or expansion of the Columbia River water resource development system, including hydroelectric power-peaking aspects of the hydro-thermal program, should be reviewed by the river management agencies to insure that the plans are consistent with the above strategy for abatement of nitrogen supersaturation problems. In order that control strategies can be developed and implemented on a timely basis, this review should be completed and provided to the regional nitrogen control council by January 1972.